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Original Article

Effects of Transcutaneous Electrical Nerve Stimulation depending on Frequency and Intensity for Postural Sway during Sit to Stand with Stroke Patients

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Purpose: The application of transcutaneous electrical nerve stimulation (TENS) is beneficial for joint movements, inhibition of spasticity, and the improvement of walking ability in patients with chronic hemiplegia. This study aimed to identify the effect of the application of TENS to the knee extensor on the affected side with respect to postural-sway distance and velocity during the sit-to stand movement.

Methods: We included 19 patients with post-stroke hemiplegia in this study. They underwent measurements during the sit-to stand movement on a force plate with 5 different stimulation dosages applied over 7 s:No TENS, high-frequency and high intensity TENS, high-frequency and low intensity TENS, low-frequency and high intensity TENS, and low-frequency and low intensity TENS The 5 different condition were administered in random order.

Results: The group that received TENS application exhibited a significant decrease in path length and average velocity of center of pressure (COP) displacement compared with the group that did not receive TENS application. TENS dosage at low frequency (3Hz) and high intensity yielded a significant decrease in path length, average velocity, mediolateral distance and anteroposterior distance of COP displacement ($p<0.05$).

Conclusion: Our results demonstrated the effectiveness of the application of low-frequency TENS on STS performance. These findings provide useful information on the application of TENS for the reduction of postural sway during the sit-to-stand movement after stroke.

Keywords: Transcutaneous Electrical Nerve Stimulation, Postural balance, Stoke

Ⅰ. Introduction

Patients with hemiplegia after stroke also exhibit dysfunctions such as visual impairment, movement disorders, cognitive impairment, perception and sensory impairment, and language disorders.[1,2] In particular, movement disorders induce postural control problems because of sensorimotor damage.[2-4] Most importantly, one of the most common symptoms after stroke is weakness on the paralyzed side caused by an imbalance in muscle strength; as a result, patient with hemiplegia have asymmetric weight bearing on one side which exacerbates the ability of balance.[5]

Difficulties in controlling balance result in many problems in activities of daily living.[6] Among others, the sit-to-stand (STS) performance precedes ambulation. This is a movement that is used repeatedly during the basic activities of daily living.[7] Individuals with stroke take a long time to perform STS, more than elderly people with no neurological disease.[8] Cheng et al[9] reported that patients with stroke show lower weight bearing in their paretic limb during STS.

Recent studies demonstrated the effectiveness of

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transcutaneous electrical nerve stimulation (TENS) for balance control and reported its benefits on joint movements, inhibition of spasticity, and improvement of walking ability in patients with chronic hemiplegia.[10,11] In addition to pain modulation, TENS also affected upper motor neurons and motor cortical excitability via afferent stimulation.[12] Dickstein et al [10] reported the effect of subthreshold TENS stimulation on postural sway via high-frequency application to the gastrocnemius muscle in healthy adults.

For therapeutic purposes, TENS is used at the low frequency of 1~4Hz and at the high frequency of 50~120Hz.[13] TENS intensity is classified into low-intensity (used to detect electrical stimulation) and high intensity (used to render muscle contraction visible).[14]

These studies only reported the effects of TENS stimulation on static balance in individuals who have experienced stroke or in healthy subjects. No study has investigated the effects of various intensities and frequencies of TENS on dynamic balance. Therefore, the aims of this study were as follows: 1) to apply various intensities and frequencies of TENS to activate somatosensory information, to investigate its effects on STS performance regarding dynamic balance.; and 2) to determine how to apply TENS most effectively for dynamic balance.

Table 1. Characteristics of the participants

Variable	Mean ± SD
Age (years)	54.1 ± 14.5
Height (cm)	168.3 ± 7.6
Weight (kg)	68.8 ± 8.7
Post-stroke duration (years)	0.6 ± 0.4
Type of stroke	
hemorrhagic/ischemic	8 / 11
Sex	
male/female	16 / 3
Paretic side	
left/right	13 / 6

II. Methods

1. Subjects

Nineteen patients with hemiplegia (16 men and 3 women) volunteered to participate in this study (Table 1). The inclusion criteria used in this study were as follows: 1) ability to perform STS independently, 2) score of 24 points or more on the MMSE-K evaluation without cognitive disabilities, 3) absence of tolerance to the surface electrode, and 4) voluntary participation in the study after receiving a sufficient explanation of the research. Individuals who had an orthopedic disease in their lower extremities or had cerebellar lesion with neurological diseases other than stroke were excluded from the study. All experiments were performed after the patients provided consent.

2. Experimental methods

1) Measurements

(1) Experimental equipment

A force plate (Balancia, Mintosys, Korea) was used to measure the displacement of the COP(Center of pressure) during STS performance. COP data were collected at a 100Hz sampling frequency and analyzed offline using a dedicated software (Balancia 2.0). TENS (Microsteam, Medel GmbH, Germany) was applied at various intensities and frequencies.

(2) Procedure

To avoid their disturbance, experiments were performed in a quiet room. In order to stimulate the quadriceps muscle, TENS electrodes (5x5cm) were attached to the medial and lateral part of the knee joint.[15] Stimulation consisted of a biphasic pulse with duration of 200μs. The high frequency adopted was 99Hz and the low frequency was 3Hz.[13] To determine intensity, low intensity was adopted starting at 0.01mA, without minimum visible contraction. High intensity was applied to the extent that the level of minimum visible contraction was induced, without being uncomfortable.[14]

Five variables were measured during STS performance using the force plate. 1) weight-symmetry ratio, which was calculated by dividing the average vertical force (in newtons) of the paretic limb by that of the non-paretic limb; 2) path length, which represents the total distance traveled by the COP; 3) mediolateral distance, which represents the amplitude of the variability of the COP excursion in the mediolateral direction; 4) anteroposterior displacement, which represents the amplitude of the variability of the COP excursion in the anteroposterior direction; and 5) average velocity of COP displacement, which represents the total distance traveled by the COP divided by testing time.

The force plate was placed under both feet and participants were seated with their arms crossed at chest level, for evaluation. During the evaluation, participants had to watch a point with a diameter of 15cm that was presented 3 m in front of the participants. The STS was performed using a chair without armrests that was adjusted to the knee joint and ankle angles to maintain them at approximately 90°. If the participants were not able to perform the STS movement, the height of the chair was raised, to reduce the knee-flexion angle. The first 2 trials were performed to obtain familiarization with the STS movement. An average of 3 subsequent STS trials was used for analysis. A break of 1 min was inserted between each trial, to prevent fatigue. STS was started with beep sounds that were delivered for 7 s. Before each trial, the individuals were given the instruction "When you hear the beep, count to 3 and then stand up comfortably".

The subjects performed the STS movement in a random order of the 5 following conditions: 1) no application of TENS (No TENS), 2) application of high frequency, high-intensity TENS (HFHI), 3) application of high frequency, low-intensity TENS (HFLI), 4) application of low frequency, high-intensity TENS (LFHI), 5) application of low frequency, low-intensity TENS (LFLI). To prevent a carry-over effect, an interval of 24 h was inserted between each condition.

3. Statistical analyses

All data analyses were performed using the SPSS ver. 18.0 software. For each variable, the mean values of 3 identical trials were used for analysis. The Shapiro-Wilk test was used to assess normalization. We performed a paired t test to compare the differences between conditions with orwithout the application of TENS. One-way repeated measures ANOVA was used to compare the effects of the 4 TENS conditions (HFHI, HFLI, LFHI, and LFLI). The post-hoc Bonferroni method was used. A significance level of 0.05 was set for all analyses.

III. Results

1. Differences in postural sway with or without the application of TENS

The path length of the COP displacement in the groups with TENS application (TENS groups) was significantly smaller than that observed in the group without TENS application (No TENS group). The average velocity of COP displacement in the TENS Groups was significantly smaller than that recorded in the No TENS group ($p<0.05$) (Table 2).

Variable	TENS Groups	No TENS	t
Path length (cm)	79.64 ± 17.20	71.05 ± 15.27	-3.75*
Average velocity (cm/s)	11.38 ± 2.46	10.15 ± 2.18	-3.75*

Table 2. Comparison of path length and average velocity of COP displacement between the TENS and No TENS conditions
*p<0.05

2. Effects of TENS on balance

1) Path length of COP displacement

There was a significant difference in the path length of the COP displacement among the between TENS groups ($p<0.05$), depending on the frequency and intensity of TENS. According to the post-hoc analysis of each group, there was no significant difference in the path length of the COP displacement between the HFHI and HFLI conditions ($p>0.05$). However, there was a significant difference in the path length of the COP displacement between the LFHI and HFHI and HFLI conditions ($p<0.05$). Although the difference in the path length of the COP displacement between the LFHI and LFLIconditions ($p>0.05$). However, there was a significant difference in the path length of the COP displacement between the LFHI and HFHI and HFLI conditions ($p<0.05$). Although the difference in the path length of the COP displacement between the LFHI and LFLIConditions was not significant, that observed for LFHI was lower than LFLI on average ($p>0.05$) (Table 3).

2) Mediolateral distance of COP displacement

There was a significant difference in the mediolateraldistance of the COP displacement among TENS groups ($p<0.05$),

Table 3. Displacement and average velocity of the COP

	HFHI	HFLI	LFHI	LFLI	F-value
Path length (cm)	71.05 ± 15.26 †	71.33 ± 13.35 †	65.34 ± 12.04	69.75 ± 16.33	6.92*
Mediolateral (cm)	47.18 ± 12.58 †	47.75 ± 11.39 †	43.30 ± 9.71	47.02 ± 14.15	5.17*
Anteroposterior (cm)	43.37 ± 1.82 †	42.86 ± 1.54 †	40.07 ± 1.57	41.76 ± 1.74	5.21*
Average velocity (cm/s)	10.15 ± 2.18 †	10.19 ± 1.90 †	9.33 ± 1.72	9.96 ± 2.33	6.91*

HFHI : high frequency and high intensity, HFLI : high frequency and low intensity, LFHI : low frequency and high intensity, LFLI : low frequency and low intensity
*p<0.05, † Significant difference compared with LFHI

Table 4. Weight-symmetry ratio

	No TENS	HFHI	HFLI	LFHI	LFLI	F-value
Weight-symmetry ratio	0.66	0.67	0.67	0.65	0.66	0.57

HFHI : high frequency and high intensity, HFLI : high frequency and low intensity, LFHI : low frequency and high intensity, LFLI : low frequency and low intensity

Depending on the frequency and intensity of TENS. According tothe post-hoc analysis of each group, there was only a significant difference in the mediolateral distance of the COP displacement between the LFHI and the HFHI and HFLI conditions (p〈0.05) (Table 3).

3) Anteroposterior distance of COP displacement

There was a significant difference in the anteroposterior distance of the COP displacement among TENS groups (p〈0.05), depending on the frequency and intensity of TENS. According to the post-hoc analysis of each group, there was only a significant difference in the anteroposterior distance of the COP displacement between the LFHI and the HFHI and HFLI conditions (p〈0.05) (Table 3).

4) Average velocity of COP displacement

There was a significant difference in the average velocity of COP displacement among TENS groups (p〈0.05), depending on the frequency and intensity of TENS. According to the post-hoc analysis of each group, therewas a significant difference in the average velocity of COP displacementbetween the LFHI and the HFHI and HFLI conditions (p〈0.05). The average velocity of COP displacement was not significantly different between the LFHI and LFLI conditions (p〉0.05) (Table 3).

3. Effect of TENS on weight symmetry ratio

The weight-symmetry ratio was calculated by dividing the rate of non-weight bearing of the affected side by the body weight bearing rate of the non-affected side. This ratio is 1.00 when in full symmetry; if it is 〈 1.00, the affected side has a reduced in weight bearing8. There was no significant difference in weight-symmetry ratio between each condition (Table 4).

IV. Discussion

To investigate the frequency and intensity of TENS that affect STS performance in patients with hemiplegia, this study measured the average velocity and distance of COP displacement, as well as weight-symmetry ratio. The groups that received TENS had a significant difference in path length and average velocity of COP displacement compared with the group that did not receive TENS. Moreover, there was a significant difference among the TENS conditions regarding path length, mediolateral distance, anteroposterior distance and average velocity of COP displacement (p〈0.05). The results of this study showed an effect on STS performance of low frequency, high-intensity TENS compared with high-frequency TENS. In general, STS performance can be divided into 4 stages.[7] In the first stage, patients flex their hip and tilt their trunk forward, to reduce the joint moment of the hip and knee joints. In the second stage, before raising the buttocks, the knee joint is a little extended and the ankle joint is slightly dorsiflexed. In the third stage, immediately after the buttocks are released, the hip and knee joint are extended sequentially. The ankle joint is slightly dorsiflexed and then slightly plantarflexed. The fourth stage includes the movement of the trunk and lower limbs until the individual is standing. The STS movement is finished when the individual is accommodated in the upright position stably. The first and second stages are performed before the buttocks are raised, whereas the third and fourth stages are performed after the buttocks are raised.

COP displacement during the fourth stage of STS on the foot is as follows: first, the COP temporarily moves to the heel. Second, the COP suddenly moves to the forefoot. Third, it goes slightly back to the heel. Fourth, the STS movement is completed after the individual has adopted an upright position. LFHI yielded the lower COP displacement in our study.

Various muscles are used during STS performance. The ankle dorsiflexor is activated to stabilize the leg while the trunk flexes at the beginning of the STS movement.[16] The ankle plantarflexor is activated to adjust the forward movement of the trunk. However, the paretic knee extensor has the highest correlation with STS performance in patients with chronic stroke.[8] Therefore, in this study, we measured the displacement of the COP to determine the effects of TENS on the knee extensor during STS performance.

The displacement of the COP can be expressed as its path length and average moving velocity, which can be measured with exactitude.[17] Human joint movements are activated by muscles and are expressed as 2 planes: anteroposterior and the mediolateral plane.[18] To investigate the stability of the STS performance in this study, we measured COP displacement in these 2 planes.

In our study, the mediolateral COP displacement was larger the than anteroposterior displacement during the performanceof the STS movement by patients with stroke. In a previous study, the movement of the anterioposterior displacement of the COP was larger than the mediolateral displacement during the performance of the STS movement by healthy people.[7] Compared with the results of previous studies, patients with stroke seem to have an insufficient ability for postural adjustment in mediolateral sway during the STS movement.

In this study, the LFLI and LFHI conditions yielded a significant decrease in the path length, mediolateral distance, anteroposterior distance, and average velocity of the COP. In accordance with previous studies, the application of TENS contributed significantly to the decrease in the path length and average velocity of the COP.[18] However, there was no significant difference in the displacement in the weight symmetry ratio. However similar to that reported by previous studies, the weight distribution on the non–affected side was higher than the weight distribution on the affected side.[19]

TENS evidently affected the excitability of the motor cortex in a previous study.[18] In this study, LF yielded a significant decrease in the path length and average velocity of the COP compared with HF. This seems to be represented by the activation of a different central nervous system because of the different frequency of electrical stimulation. Zhang et al[20] reported the mechanism underlying frequency specificity using Functional MRI. The contralateral parietal lobe, anterior cingulate cortex, nucleus accumbens, and pons are related by highfrequency (100Hz) electrical stimulation. The contralateral primary motor area, supplementary motor area and superior temporal gyrus are related by low frequency (2Hz) electrical stimulation.[20] Moreover experiments performed in the rat showed that the neurotransmitter secretion was different.

The high–frequency electrical stimulation led to the secretion of didorphin, with no significant reduction in the edema of the ankle joint. However, low–frequency electrical stimulation led to the secretion of endomorphins, enkephalins and β–endorphin, with significant reduction in ankle–joint edema.[21,22]

A previous study reported that low–intensity electrical stimulation on the knee of a healthy adult helped balance control.[23] Ross et al[24] showed the effectiveness of electrical stimulation applied to the ankle muscles in reducing postural sway. This is because the electrical stimulation induced the activation of mechanoreceptors in weight–bearing joints.[25] Low–frequency electrical stimulation was applied in this study. Therefore, we assumed that it affected the primary motor cortex and supplementary motor area and helped STS performance.

This study applied a high-intensity electrical stimulation; moreover, the application of high-frequency electrical stimulation affected muscle contraction. Chesterton et al[14] reported that electrical stimulation at high frequency/high intensity induced a tetanic muscle contraction. In accordance with that previous study, therefore, we considered that the positive effects of high-intensity electrical stimulation on STS performance were the result of muscle contraction.

The application of TENS strengthens the somatosensory stimuli via direct stimulation of the afferent nerve,and help the central nervous system accept information about the position and movement of the body.[26] This mechanism involves information from the skin, ligaments, joint capsules and muscle receptors.[27] For this reason, even though TENS affects the skin, it contributes to the potential proprioceptive stimulation of the central nervous system.[18] Furthermore, TENS stimulation might result in motor cortex excitability by mediating the cerebral cortex.[12,28] Several studies have shown that TENS affects balance.[18,29,30]

Despite the displacement of the COP, the application of TENS did not yield a significant difference in the weight-symmetry ratio. The increase in the weight-bearing rate of the paralyzed side implies increased use of the lower limb on the paralyzed side during STS performance in patients with stroke.[8] However, the weight-bearing rate did not increase after TENS in the paralyzed side in this study. In addition, the number of subjects included in the study was small; thus, it is difficult to generalize our results. Future research need to consider these aspects.

In conclusion, our results demonstrated the effectiveness of the application of low frequency TENS on STS performance; however, the application of high-frequency TENS was not effective. The results of this study provide evidence that focuses on paretic knee extension to improve STSperformance in individuals with chronic stroke. In order to improve the dynamic balance of stroke patients, stimulation of the low frequency is more effective than high-frequency stimulation of TENS. These results provide useful information for future research.

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